

PATENT SPECIFICATION

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(54) ENERGY SUPPLY PLANT, MORE ESPECIALLY FOR AIRCRAFT, COMPRISING AN ASYNCHRONOUS GENERATOR DRIVEN AT VARIABLE SPEED BY A PRIME MOVER

(71) We, SIEMENS AKTIEN-GESELLSCHAFT, a German Company of Berlin and Munich Germany do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to an electrical energy supply plant suitable for producing a substantially constant frequency alternating current from a variable speed prime mover.

Such a primer mover is, for example, an electric motor, an internal combustion engine or a turbine. Prime movers like these are used on board ships and in aircraft.

According to the present invention there is provided an electrical energy supply plant suitable for generating a substantially constant frequency alternating current from a variable speed prime mover, the supply plant comprising first and second asynchronous generators having rotors which are mechanically coupled to each other so as to be simultaneously rotatable by such prime mover, the first generator having stator connections providing output means of the supply plant and the second generator having a rotor winding connected to supply to a rotor winding of the first generator variable slip frequency for maintaining the stator current frequency of the first generator substantially constant, there being a constant frequency excitation source coupled to a stator winding of the second generator by an electrical coupling arranged to supply to said stator winding all the stator excitation current of the second generator.

The frequency of the excitation source is not variable in dependence upon the speed of the prime mover, but is constant without necessarily having to agree with the desired (synchronous) supply plant frequency. The supply plant thus provided operates as a generator regardless of whether the actual rotation frequency owing to the prime mover

is higher or lower than the desired supply plant frequency. The excitation source does not constitute merely a powerless timer, but a source of excitation active and reactive power.

Ordinary asynchronous machines are suitable for use as the first and second generators, without feedback windings and without any special dimensioning by way of angular positions of windings. Also, by reason of the manner of operation the phase sequence between the first and second generators need not be interchanged.

According to one development of the invention, the supply plant can comprise a series of pairs of asynchronous generators interconnected as are the first and second generators. The excitation source is connected to the second generator of the last pair in such a series, and the more pairs there are the smaller need be the output power of the excitation source. This may in some cases afford substantial advantages.

Some advantages attainable by utilisation of the invention reside in the use of simpler, lighter and cheaper asynchronous generators as compared with synchronous generators; a substantial reduction of the excitation energy which has to be supplied; a low non-linear distortion factor of the voltage possibly without any necessity for filters; substantially inertialess regulatability and hence excellent regulating dynamics; and construction without slip rings and consequently operation with little servicing.

For a better understanding of the invention and to show how the same may be carried into effect reference will now be made, by way of example, to the accompanying drawing in which:

Figure 1 is a diagrammatic illustration of one embodiment of the present invention;

Figure 2 is an energy flow diagram corresponding to Figure 1; and

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Figure 3 illustrates a second embodiment of the present invention.

Figure 1 shows a first three-phase asynchronous induction generator 2 the rotor 2b of which is connected by a shaft 1a to a turbine, for example of an aircraft, which is driven at greatly variable speed. The first asynchronous generator 2 supplies electrical energy from its stator winding 21 into an electrical supply system R, S, T. The rotor 2b is provided with a three-phase winding 22 and is rigidly connected to the rotor 3b of a second three-phase asynchronous induction generator 3 the rotor of which supports a three-phase current winding 32. The second generator 3 has a lower rated power than the first generator 2 and the stator 3a of the second generator 3 has a three-phase current winding 31 which is connected to an alternating-current excitation source of constant frequency comprising a frequency changer 4 and an auxiliary exciter arrangement 5. The excitation source is designed to supply to the stator winding 31 all the stator excitation current of the second generator 3. Instead of the particular type of excitation source illustrated, any other available alternating-current source of sufficient output power and constant frequency may be employed.

The asynchronous generators 2 and 3 are advantageously constructed without slip rings and the auxiliary exciter arrangement 5, necessary for an independent supply plant, consists in the usual way of an exciter machine constructed as a synchronous machine 5e having no slip rings, and of a synchronous auxiliary exciter machine 5a which excites the machine 5e. The auxiliary exciter machine 5a is provided in the usual way with external permanent magnet poles 5b and an induction winding 5c which is disposed in the rotor and which is connected through a rotating rectifier arrangement 5d to the direct-current exciter winding 5f of the synchronous machine 5e. The stator winding 5g of the synchronous machine 5e feeds the stator winding 31 of the induction machine 3 with electrical energy at the required constant frequency of, for example, 400 c/s, through the frequency changer 4.

For an explanation of the manner of operation of the supply plant of Figure 1 it will be assumed that the two asynchronous generators 2 and 3, combined to form a machine pair M1, are constructed on a bipolar basis (with one pole pair) and that the actual speed of the turbine 1 is below the synchronous speed of 24,000 r.p.m., the actual speed of the turbine 1 fluctuating in the range from 10,000 to 20,000 r.p.m.

There is generated in the rotor winding 32 of the second asynchronous generator 3, by the constant frequency excitation of the winding 31, a voltage having a frequency which

is determined by the difference between the stator frequency and the rotor frequency. Thus, when the shaft 1a is running at 10,000 r.p.m., there is set up in the rotor winding 32 a voltage of frequency $400 \text{ c/s} - 167 \text{ c/s} = 233 \text{ c/s}$. When the shaft 1a is running at 20,000 r.p.m., the rotor voltage frequency is $400 \text{ c/s} - 333 \text{ c/s} = 67 \text{ c/s}$. The rotor winding 22 of the first asynchronous generator 2 then generates, assuming the same winding direction, a rotating field which rotates with the sum of the rotation frequency of the shaft 1a and the frequency of the voltage in the rotor winding 32 feeding the rotor winding 22. Consequently the rotation frequency of this rotating field in the first asynchronous machine 2, and hence the frequency of the voltage fed into the supply system R, S, T, are always equal to the frequency preset by the frequency changer 4, independently of the speed fluctuation of the shaft 1a. For example, when the shaft 1a rotates at a speed of 20,000 r.p.m., the stator frequency is $67 \text{ c/s} + 333 \text{ c/s} = 400 \text{ c/s}$, and when the shaft 1a rotates at a speed of 10,000 r.p.m., it amounts to $233 \text{ c/s} + 167 \text{ c/s}$, i.e. again 400 c/s.

Desired variations in the output frequency of the asynchronous generator 2 may be effected linearly with respect to time in dependence upon the operation of the frequency changer 4. In addition, the voltage value and phase of the output from the generator 2 may be varied linearly with respect to time in dependence upon the operation of the frequency changer 4, whilst maintaining the output frequency itself constant.

A typical example of percentage contributions to the total output electrical power from the generator 2 is indicated in Figure 2. According to this example, at the lowest speed of rotation of 10,000 r.p.m., which requires the greatest amount of energy, of the total generator output $P = 100\%$, about 42% is supplied by the generator itself from mechanical energy, while about 58% is supplied as electrical slip energy *via* the second asynchronous generator 3. The latter in turn generates about 25% of P from mechanical energy, so that the electrical excitation energy supplied by the excitation source must amount to about 33% of the generator output P . This frequency changer output energy, expressed as a percentage of P , decreases for example from 33% to 25% when, instead of the assumed speed fluctuation range of 1:2, the range of 1:1.7 is taken as a basis.

The number of pole pairs of the second asynchronous generator 3 fed by the frequency changer 4 may be made different in the stator and in the rotor of the generator 3. That is to say, taking as a basis the already described subsynchronous operation of the generators 2 and 3, the number of pole pairs of for example the rotor 3b may be greater, more especially two to four times greater,

than the number of pole pairs of the stator 3a. The generator 2 driven at a speed between 10,000 and 20,000 r.p.m. would then become constructed on a bipolar basis as in the described example, while the asynchronous generator 3 is constructed on a bipolar basis in the rotor. In this way, the stator winding 31 of the asynchronous generator 3 only has to be excited with $1/2$ to $1/4$ of the frequency to be supplied by the winding 21. The output frequency of the frequency changer 4 can consequently be reduced in this case by $1/2$ to $1/4$, and in the case of a generator frequency of 400 c/s, to 200—100 c/s. The result is thereby achieved for example that, owing to the lower switching frequency, the switching losses of thyristors of the frequency changer 4 can be reduced to the benefit of design of the frequency changer. On the other hand, it is thus also possible, in the case of the direct frequency changer, to raise its input frequency while retaining the same output frequency, in the example 100 or 200 c/s. One thus increases the frequency swing in the direct frequency changer, whereby the curve form of the frequency changer output voltage, and hence also the curve form of the voltage of the generator 2, can be improved.

Figure 3 shows an electrical energy supply plant wherein at least one further generator pair M2 is connected between the frequency changer 4 and the generator 3. The generator pair M2 consists of a third asynchronous generator 6, the rotor of which is mechanically connected to the rotor of the second asynchronous generator 3, and a fourth asynchronous generator 7 which is connected to the rotor and the asynchronous generator 6 both mechanically and electrically. In this way, an electrical coupling is maintained from the frequency changer 4 to the stator winding 31 of the second asynchronous generator 3, via the various illustrated stator and rotor windings. Because of the interposition of further generator pairs such as M2 and M3, the excitation energy to be supplied from the frequency changer 4 is decreased in accordance with an exponential series as more generator pairs are added. The extra generators may be of constantly decreasing size, which in some cases affords the possibility of a simpler frequency changer construction (for example switching elements which are transistors as opposed to thyristors), or in an increase of the output power of the generator cascade with a given frequency changer.

The invention can be utilised in all types of generator and prime mover combination in which the actual rotation frequency of the generator does not agree with the frequency of the generator voltage or that coming from the supply system, as for example in the case of shaft-mounted generators on ships, airborne generators, system-tie frequency converters and impulse power converters.

In certain known arrangements, for example system-tie frequency converters and impulse power converters, the rotor winding 22 of the machine 2 would be supplied by a frequency converter (frequency changer) with the necessary supplementary slip frequency energy for providing constant frequency generator output voltage. Such slip frequency would have to be regulated in accordance with the speed fluctuations, whereas in the illustrated arrangement comprising the second asynchronous generator 3 it is unnecessary for the frequency changer 4 to supply a variable frequency and a constant excitation frequency is used, without needing slip rings, for the slip energy supply of the generator 2. In addition to this advantage, the magnitude of the excitation energy to be supplied to the system is considerably reduced by the inclusion of the second generator 3.

A further technique conventional with shaft-mounted generators such as airborne generators is to connect on the output side of a synchronous generator, supplying a voltage the frequency of which is variable in accordance with the speed, a frequency changer for making the output frequency constant. The frequency changer must therefore be rated to withstand the full generator output, whereas with the described and illustrated embodiments the frequency changer only has to withstand a relatively small amount of energy ($1/3$ of the total generator output in the example). This is particularly advantageous when one realises that the frequency changer constitutes one of the most costly parts of the plant. A further advantage, more especially in the case of airborne generators, resides in that plants such as those illustrated and described, comprising asynchronous generators and a frequency changer, have substantially no magnetic inertia as compared with synchronous machines. The described plants thus give superior regulating dynamics, which is particularly important in this application.

Another advantage resides in that the ripple of the generated voltage is low for the described plants, because the highly harmonic-generating frequency changer supplies only for example $1/3$ of the total generator output power. The cost of filtering the generator output, if filtering is necessary at all, can be reduced. Filtering is more likely to be desirable in airborne generators because these require a very low ripple content.

WHAT WE CLAIM IS:—

1. An electrical energy supply plant suitable for generating a substantially constant frequency alternating current from a variable speed prime mover, the supply plant comprising first and second asynchronous generators having rotors which are mechanically coupled to each other so as to be simultaneously rotatable by such prime mover, the first generator

5 having stator connections providing output
means of the supply plant and the second
generator having a rotor winding connected
to supply to a rotor winding of the first
generator variable slip frequency for main-
10 taining the stator current frequency of the
first generator substantially constant, there
being a constant frequency excitation source
coupled to a stator winding of the second
generator by an electrical coupling arranged
to supply to said stator winding all the stator
excitation current of the second generator.

15 2. An energy supply plant according to
claim 1, wherein the first and second genera-
tors are constructed without slip rings.

3. An energy supply plant according to
claim 1 or 2, wherein the constant frequency
excitation source comprises a static frequency
changer.

20 4. An energy supply plant according to any
one of the preceding claims, wherein the con-
stant frequency excitation source comprises a
synchronous auxiliary generator arrangement
having rotor means mechanically connected to
25 the rotors of the first and second asynchronous
generators.

5. An energy supply plant according to any
one of the preceding claims, wherein the
second asynchronous generator is constructed
30 with different numbers of pole pairs in the
stator and in the rotor respectively.

6. An energy supply plant according to
claim 5, wherein the second asynchronous
generator has a higher number of pole pairs
35 in the rotor than in the stator to provide

for subsynchronous operation of the first and
second generators.

7. An energy supply plant according to any
one of the preceding claims, wherein said
electrical coupling between the constant fre- 40
quency excitation source and said stator wind-
ing of the second generator comprises at least
one machine set consisting of third and fourth
asynchronous generators the rotors of which
are mechanically coupled with the rotor of the 45
second asynchronous generator, the electrical
coupling being *via* the stator of the fourth
generator, the rotors of the third and fourth
generators which rotors are electrically con-
nected to each other, and the stator of the 50
third generator.

8. An energy supply plant according to any
one of the preceding claims, wherein the first
and second generators are so constructed that
the second generator has a lower rated power 55
than does the first generator.

9. An electrical energy supply plant sub-
stantially as hereinbefore described with
reference to Figure 1 or 3 of the accompany-
ing drawing. 60

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